Subsidence Monitoring of Offshore Platforms in Malaysian Waters Using GPS Technique

Rusli Othman[1]
Halim Setan[2]
Department of Geomatic Engineering
Faculty of Geoinformation Science and Engineering
Universiti Teknologi Malaysia
81310 UTM, Skudai, Johor, Malaysia
rusli@fksg.utm.my[1]
halim@fksg.utm.my[2]

ABSTRACT

Between the east coast of Malaysia Peninsula and the west coast of Sabah and Sarawak lies South China Sea, which locate more than a hundred of offshore platforms, which extract oil and gas for major oil production companies such as PETRONAS and SHELL. One of the major problems of these platforms is the occurrence of subsidence, which may cause disaster to man and platform itself. Since these offshore platforms are located hundreds of kilometers from shore, the GPS technique is seemed the only possible method that is able to carry out subsidence monitoring for geodetic method. This paper will look at the potential of GPS technique for monitoring of subsidence of these platforms in Malaysian waters. The existence of MASS stations in Peninsular Malaysia and in Sabah and Sarawak that continuously logging in data throughout the years give an option for carrying out subsidence monitoring of offshore platforms. The Bernese GPS Software is used in the processing of these GPS data and the output will then use for the detection of subsidence of these offshore platforms. This paper will also discuss the strategy of data processing and subsidence detection of the offshore platforms located in the Malaysian waters.

INTRODUCTION

Oil and gas remain the energy source in Malaysia, where each of them contributes almost 33% and 41% of total energy generation. Most of our hydrocarbon (oil and gas) reserves are mostly located 120 – 250 km from offshore and it requires very high precision, reliable and highly available positioning tool for monitoring of subsidence at offshore platforms. Due the withdrawal of gas from beneath the seabed, the seabed experiences a compaction, which may cause the platforms to experience subsidence. Two major petroleum explorers in South China Sea are PETRONAS and SHELL and these petroleum companies have involved in erecting offshore platforms for petroleum and gas production in Malaysian waters. Determination of subsidence of offshore platforms can be carried out either by using geotechnical, structural or geodetic method. In this study, the geodetic method was used and it involves the reference network of Global Positioning System (GPS) observation.

GLOBAL POSITIONING SYSTEM (GPS)

Due to the constantly growing technological progress in all fields of engineering and, connected with it, the increasing demand for higher accuracy, efficiency, and sophistication of the deformation measurements, geodetic engineers have continuously search for better monitoring techniques and have to refine their methods of deformation analysis. The advert of space techniques such GPS has opened a new dimension in data acquisition which involves offshore structures such as gas and oil platforms which are located hundreds of kilometers offshore. A suitable technique of data acquisition has to be identified in order high accuracy observation can be obtained and later use in deformation analysis.

The establishment of a network of control points on offshore platforms as well as on land requires a measuring tool that can give us a very high precision and a reliable data that are necessary for deformation or subsidence monitoring. A number of control stations between datum points (i.e. control points on land) and object points (i.e. control points on offshore platforms) need to be established for measurement of baseline vectors (ΔX, ΔY, ΔZ). In order to detect and measure the vertical motion or subsidence of offshore oil platforms, GPS is considered as the best tool to determine relative position between control stations because GPS allows us to achieve a desirable precision (i.e. $\pm$0.1ppm) that is necessary for subsidence monitoring (Ashkenazi & Ffoulkes-Jones (1990), Leick (1995), Krinjen & Hues (1995)).

THE MALAYSIA ACTIVE GPS SYSTEM (MASS)

The Malaysia Active GPS System (MASS) or Zero Order Network is a network of GPS permanent stations established by the Department of Surveying and Mapping Malaysia throughout the whole country of Malaysia. These stations automatically record and archive data from available GPS satellites for accurate position determination 24 hours a day. MASS will provide code range and carrier phase data in support of post processing applications. The acquired GPS data is available for distribution to the public by the Geodesy Section, Geodetic Survey Division, Department of Survey and Mapping, Malaysia (DSMM).

The main objectives of the establishment of these MASS permanent stations are to analysis the accuracy of the existing geodetic network and to provide GPS data to all users in Malaysia for carrying their works for the development of the country. Another important objective is to provide supports for researchers for a wide range of applications for geodesy, surveying, mapping, engineering, scientific and geodynamic studies in Malaysia. One recent research work is the on crustal movement due to the impact of earthquake that created killer waves or tsunami in this part of Southeast Asia region.

MASS Sites

There are fifteen mass stations that have been established at selected sites as shown in Fig. 1. Table 1 shows the list of MASS sites and their type of receivers and antennas. Eight of these MASS stations are located in Peninsular Malaysia while the rest are established in Sabah, Sarawak and one in the Federal Territory of Labuan. The GPS receiver installed at MASS stations are GPS Receiver TRIMBLE 4000SSE and 4000SSI dual frequency receivers whilst the GPS antenna used are TRIMBLE Compact L1/L2 with ground plane and TRIMBLE Choke Ring with radome. These antennas are permanently mounted on pillars at appropriate locations, which provide an uninterrupted view of the surrounding sky and are inaccessible to unauthorised persons. Each permanent GPS station also consists of TRIMBLE Universal Reference Station (URS) software operating on the Windows NT system platform. All these stations are tied to local geodetic survey networks to a high degree of accuracy.

Table 1: Location of MASS stations and their type of receiver and antenna.

No.	MASS Sites	Receiver	Antenna
1.	Kuantan, Pahang	Trimble 4000SSI	Trimble Choke Ring
2.	Bintulu, Sarawak	Trimble 4000SSI	Compact L1/L2 GP
3.	Kota Kinabalu, Sabah	Trimble 4000SSE	Compact L1/L2 GP
4.	ITM Arau, Perlis	Trimble 4000SSI	Trimble Choke Ring
5.	KTPK, Kuala Lumpur	Trimble 4000SSI	Trimble Choke Ring
6.	Kuching, Sarawak	Trimble 4000SSI	Trimble Choke Ring
7.	Bukit Pak Apil, Terengganu	Trimble 4000SSI	Trimble Choke Ring
8.	Getting, Kelantan	Trimble 4000SSI	Compact L1/L2 GP
9.	Miri, Sarawak	Trimble 4000SSI	Compact L1/L2 GP
10.	Labuan	Trimble 4000SSI	Trimble Choke Ring
11.	UTM, Skudai, Johor	Trimble 4000SSI	Compact L1/L2 GP
12.	Ipoh, Perak	Trimble 4000SSI	Trimble Choke Ring
13.	Sandakan, Sabah	Trimble 4000SSI	Trimble Choke Ring
14.	Tawau, Sabah	Trimble 4000SSI	Trimble Choke Ring
15.	USM, Pulau Pinang	Trimble 4000SSI	Trimble Choke Ring

Fig. 1: Location of MASS stations in Peninsular Malaysia and Sabah and Sarawak.

Fig. 2: Example of one of the MASS station established at JUPEM's building in Kuala Lumpur.

The network of the MASS stations is remotely operated and managed from the Geodetic Data Processing Centre, Geodesy Section, Kuala Lumpur. Each MASS station records in TRIMBLE proprietary formats and convert to RINEX with the Coarse Acquisition (C/A) code, P/Y code, L1/L2 carrier phases observable. The MASS stations are set to operate at 24 hours a day and all year round. The data format for all MASS stations is supplied in one-hour blocks with either in RINEX format or DAT format files (synchronous data) and these GPS data can be obtained from the Geodetic Data Processing Centre via the Internet.

GPS DATA OBSERVATION AT OFFSHORE PLATFORMS

An offshore platform used in this study is located in South China Sea and about 300 km from the offshore of west Peninsular Malaysia. In order, to detect subsidence that might occur at this platform, three control stations were established at the platform. The control stations at the offshore platform were observed by using TRMBLE 400 SSI Geodetic Series GPS receivers with dual frequency L1 and L2 for duration of 24 hours at the interval of 15 seconds. The control stations were located at three corners of the offshore platform. The relative orthometric heights between these control stations are determined by using levelling technique.

TECHNIQUE OF OBSERVATION

The basic concept in subsidence monitoring for offshore platforms is to employ GPS relative positioning of the offshore platform with respect to the stable control stations on shore. The technique used for GPS observation is relative positioning technique (Fig. 3), which involves control stations on shore and three control stations established at the offshore platform. The relative static GPS observations were carried for 24 hours at 15-second interval to give the required accuracy for such a long baseline length. The GPS relative positioning was carried out to determine the coordinates of a point or points relative to a fixed, known point and points.

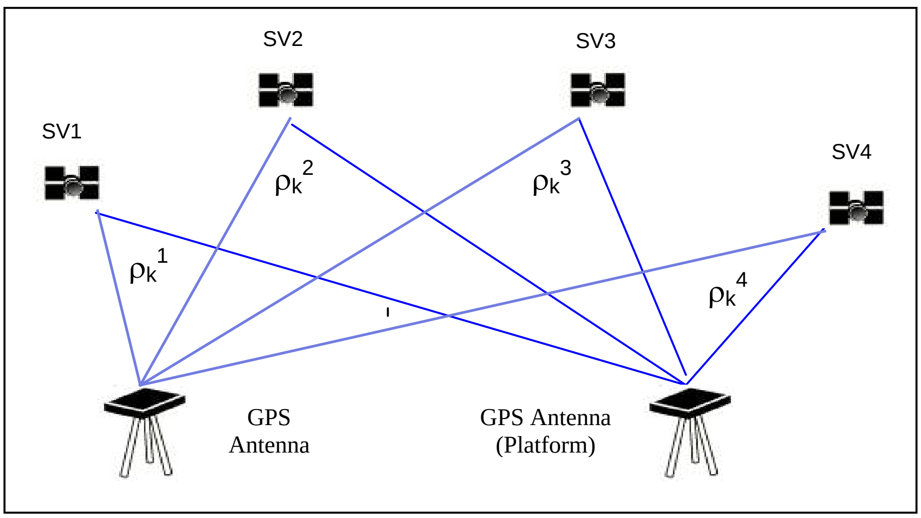

Fig. 3: Relative Positioning using GPS technique.

The deformation network used in this study will be absolute network rather than relative network as the control station (datum points) will be situated on shore, away from the area where subsidence is expected. All object points are situated on the offshore platform. The datum points are related to object points through GPS observations that will give the baseline vectors between points (Caspary, (1987); Kuang (1991 & 1996) and Halim & Ranjit (2001)).

STRATEGY FOR DETECTION OF SUBSIDENCE

The study of subsidence monitoring of offshore platforms in Malaysian waters involves the two-epoch analysis (Chen (1983), Caspary, (1987); Kuang (1991 & 1996), Rusli &

Halim (1999) and Halim & Ranjit, (2001)). GPS data from two epochs of observation, which involve GPS data from MASS stations and observed GPS data at control stations established at the offshore platforms, will be used. The Bernese GPS software will be used for processing GPS data for all control stations where baseline computation and network adjustment will be carried out. The output from Bernese GPS Software will generate the estimated coordinates of all control stations and covariance matrices for each epoch of observation. This will follows with subsidence detection process by using a computer program developed for such purpose. Fig. 4 illustrates the flowchart of the research methodology.

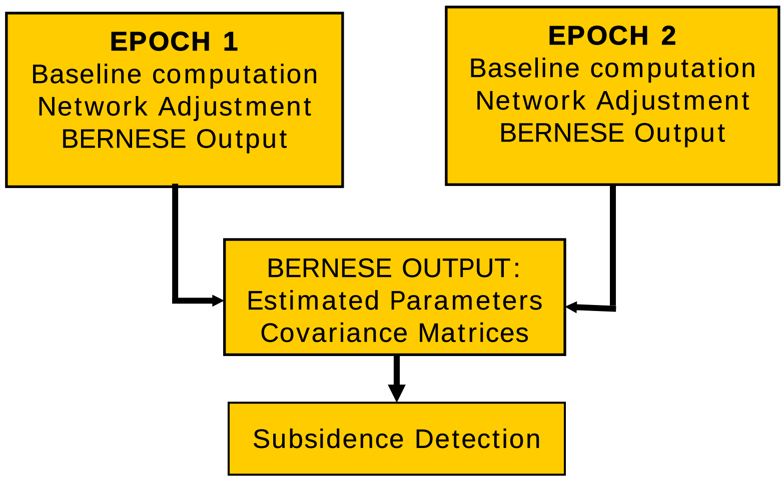

Fig. 4. Flowchart of research methodology.

DATA PROCESSING

Since the GPS baselines are hundreds of kilometers in length, therefore it requires sophisticated data processing software to achieve high accuracy results. Data from GPS receivers fixed on offshore platforms and GPS stations onshore are processed by using the Bernese GPS Software. Baseline vectors between GPS stations are later computed and analysed. Baseline determinations are made on periodic basis.

Bernese GPS Software

The Bernese GPS software was developed by a group of researchers at University of Berne, Switzerland. This software is suitable for scientific studies in surveying fields that require high precision such as first order GPS network. This software can eliminate certain errors and able to rectify any ambiguity in the processing of baselines of high precision which enable to achieve high accuracy GPS results and analysis (Rothacher & Mervart, 1996).

This software tool is particularly well suited for rapid processing of small-size single and dual frequency surveys, permanent network processing, ambiguity resolution on long baseline (up to 2000 km using high accuracy orbits), ionosphere and troposphere modeling, combination of different receiver types (antenna phase centre calibrations), simulation studies, orbit determination and earth parameter estimation, generation of so-called free network solutions. Fig.5 shows the flowchart of the Bernese GPS Software, which illustrates the common steps in the flow of GPS data processing strategy. The software is capable of giving baseline solution and network adjustment.

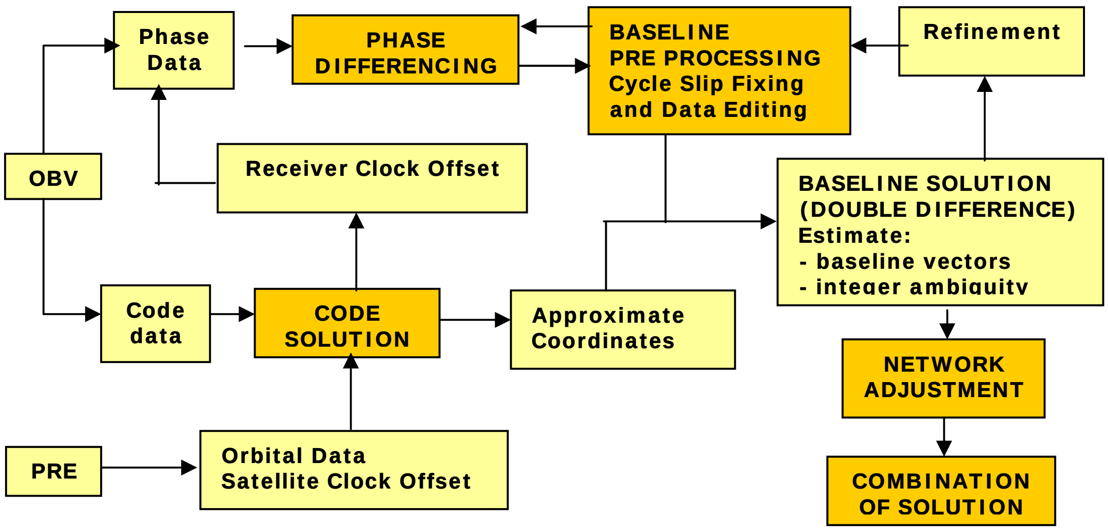

Fig. 5: The flowchart of the Bernese GPS Software. (Source: Bernese GPS Software Manual).

Bernese GPS Data Processing: Baseline Solution

Bernese GPS processing involves several steps that are requires special attention for obtaining high precision results such as code processing, phase differencing, phase-pre-processing, parameter estimation, ambiguity resolution and the combination of the solution. To resolve the ambiguities in each baseline, ambiguity free L3 (ionosphere-free) solution was first used followed by the QIF (Quasi-Ionosphere-Free) solution in baseline-by-baseline mode for all sessions.

Network Adjustment

For the network adjustment, the free network solution is used to define the geodetic coordinates with a minimum number of constraints, without fixing or totally constraining particular site coordinates. The free network solution is done by specifying the fixed station in the network as to define the apriori sites for the reference network. The shore control stations will be held fixed and will include the control stations on the offshore platforms in the combined solution. The computed station coordinates would be given in WGS84 coordinates system.

INITIAL STUDY

The study of subsidence detection for offshore platforms in Malaysian waters involves three shore control stations and three GPS stations on the offshore platform. The result from Bernese GPS Software gives the ellipsoidal heights of all the six control stations. A software that has been developed for subsidence monitoring detection between two epochs was then used. This software requires information on the difference in height of the six control stations and its standard deviation of observation. The output of this software via the Iterative Weighted Similarity Transformation (IWST) will identify the six control stations in the network that are stable or have moved.

Table 2: The heights (in meters) of the three control stations established at the two offshore platforms at two difference epochs.

Station Name	Epoch I	Epoch 2
1	3.896	3.896
2	2.387	2.387
3	7.782	7.782
4	49.949	49.913
5	49.827	49.796
6	50.467	50.445

Table 3: Result from subsidence monitoring program.

Stn	*dz*	Stat. Value vs. Conf. Level	Status
1	-0.011	23931962.492 > 4.654	Moved
2	0.025	171986793.921 > 4.654	Moved
3	-0.011	23931962.604 > 4.654	Moved
4	-0.011	95727850.480 > 4.654	Moved
5	0.020	110071548.204 > 4.654	Moved
6	0.011	95727850.480 > 4.654	Moved

The results obtained from the output of the Bernese software indicate that subsidence experienced by the offshore platforms at cm level can be detected. Results from Table 3 above indicate a significant vertical movement of the two offshore platforms.

CONCLUSIONS

From the study carried, the use of the Bernese software is considered suitable for processing long baselines. This software is able to produce high accuracy results, which are considered important and vital in subsidence monitoring survey. The differences in height between the control stations on the platform derived from levelling and GPS observations are similar in magnitude and orientation of the tilts and thus indicate the practicality of using GPS technique in subsidence monitoring especially for such a long baselines.

The existence of MASS stations throughout the peninsular of Malaysia, Sabah and Sarawak gives better option in carrying out subsidence monitoring of offshore platforms in Malaysian waters. The permanent MASS stations that operate at 24 hours a day and all year round enable surveyors and geodesists to achieve high accuracy results in point positioning that are required for subsidence monitoring.

The software developed for the purpose of subsidence monitoring used in this study indicates that the six control points established in the network for detecting of subsidence have experienced subsidence or vertical displacement.

Acknowledgements

The authors would like to thank the Department of Surveying and Mapping Malaysia and PETRONAS Carigali Sdn. Bhd. for providing GPS data used in this study.

Reference

Ashkenazi, V. & Ffoulkes-Jones, G. (1990), Millimeters Over Hundreds of Kilometers by GPS, *GPS World*. November/December 1990.

Caspary, W.F. (1987), Concepts of Network and Deformation Analysis, 1st.ed., School of Surveying, The University of New South Wales, Monograph 11, Kensington, N.S.W., 183 pages.

Chen, Y.Q. (1983), Analysis of Deformation Surveys – A Generalized Method, Department of Surveying Engineering, University of New Brunswick, Technical Report No. 94, New Brunswick.

Halim Setan & Ranjit Singh (2001), Deformation Analysis of a Geodetic Monitoring Network, Geomatica. Vol. 55, No. 3, 2001, pp. 333-346.

Rusli Othman & Halim Setan (1999). Detecting the Stability of Reference Stations in Monitoring of Subsidence Using GPS, Research Seminar on Construction, Materials & Environmental Technologies, UTM Skudai, 3-4 February 1999.

Krijnen, K, & Hues H.de. (1995), Application of GPS with sub-centimeter Accuracy for Subsidence Monitoring, Proceedings of the 5th International Symposium on Land Subsidence, The Haque, Netherlands, 16-20 October 1995, A. A. Balkema, Rottherdam, Brookfield.

Kuang Shan-Long (1991). "Optimization and Design of Deformation Monitoring Schemes." Department of Surveying Engineering, Report No. 157, University of New Brunswick, Fredericton, New Brunswick, Canada.

Kuang Shan-Long (1996). “Geodetic Network Analysis and Optimal Design: Concepts and Applications.” Ann Arbor Press, Inc.: Chelsea, Michigan.

Leick, A. (1995). “GPS Satellite Surveying.” Second Edition, John Wiley & Sons, Canada.

Rothacher, M. and Mervart, L. (1996). “Bernese GPS Software Version 4.0.” Astronomical Institute, University of Berne.